

**WHO GOES TO GRADUATE SCHOOL? ENGINEERING GRADUATES' MATH
PROFICIENCY, COLLEGE EXPERIENCES, AND SELF-ASSESSMENT OF SKILLS**

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Hyun Ro,¹ Lisa Lattuca,² & Ben Alcott³

¹ College of Education and Human Development, Bowling Green State University

² School of Education, University of Michigan

³ Faculty of Education, University of Cambridge

Abstract

Background. Increasing human resources in engineering is a key concern for the United States. While some research has considered pathways to doctoral study, there is not yet clear empirical evidence on the role of undergraduate experiences in motivating engineering undergraduates to continue to graduate school, both in engineering programs and more broadly.

Purpose/hypothesis. We investigate three influences on engineering undergraduates' decision to enter graduate school: (1) mathematics ability, (2) self-assessments of engineering skills, and (3) co-curricular experiences.

Design/method. Using data from 1,119 engineering postgraduates, we developed a hierarchical multinomial logistic model (HMLM) to analyze the relationship between prior characteristics and their observed graduate-school enrollment behavior.

Results. Mathematic ability, participation in undergraduate research, and self-assessed teamwork skills are all significant positive predictors of enrollment in an engineering graduate program, although self-assessed leadership skills are a negative predictor. For enrollment in a graduate school program outside of engineering, non-engineering community service or volunteer work was a significant predictor, but none of the self-assessed skills were predictors.

Conclusions. Our findings support past research emphasizing academic preparedness in STEM-field progression, further corroborating the claim that K–12 math education is a key policy lever. Our findings also indicate distinctive patterns between engineering and non-engineering graduate study in relation to self-assessed skills and co-curricular experiences. This should promote research on which types of preparation during college are needed for different career paths, to develop both teamwork and leadership within the industry.

Keywords: Graduate School Choice, Engineering Persistence, College Experience

WHO GOES TO GRADUATE SCHOOL? ENGINEERING GRADUATES' MATH PROFICIENCY, COLLEGE EXPERIENCES, AND SELF-ASSESSMENT OF SKILLS

The preparation of students for graduate studies in Science, Technology, Engineering, and Mathematics (STEM) fields has received considerable attention to keep up with growing demand in the STEM workforce. Recently, the Economic Policy Institute reported that the nation has more than a sufficient supply of high-skill temporary foreign employees in STEM occupations (Salzman, Kuehn, & Lowell, 2013). However, fears of increasing global competition compound the perception that there has been a lack of similarly qualified *domestic* students in STEM graduate programs. The United States cannot necessarily continue to rely on a compensatory inflow of talent from overseas (Bowen, Chingos, McPherson, & Tobin, 2009): between Fall 2011 and Fall 2012, the rates of foreign enrollments in graduate programs in science and engineering have increased by just three percent (National Science Board, 2014).

It is important to note that patterns in graduate school enrollment may vary across STEM disciplines. Specifically, engineering students might be less likely to pursue graduate study than students in mathematics, chemistry, or physics. Engineering majors and careers have attracted many working-class and first-generation students, who are particularly likely to view their undergraduate education as a tool to upward mobility, but disinclined to consider entering graduate programs (Davies, & Guppy, 1997). Also, research focusing on gender disparity in engineering has suggested that women are less likely to plan to study engineering graduate programs because of a lack of mentoring or chilly climate (e.g., Baker, Tancred, & Whitesides, 2013). Similarly, studies have found that underrepresented minority students hesitate to choose graduate studies in STEM fields (e.g., Museus, Palmer, Davis, Maramba, 2011; Cole & Barber, 2003). It is worth noting though that these studies have focused on doctoral programs as a means

to diversify STEM faculty, rather than on master's programs or professional graduate programs as a means to diversify the engineering profession.

To date, researchers have not yet considered the potential impact of engineering students' college experiences – particularly co-curricular participation, and self-assessments of their skill sets – on their graduate education choices inside and outside of STEM fields. Furthermore, while a substantial amount of research on graduate school attendance has focused on doctoral graduates, to date there has been limited research on graduate school attendance that includes master's program enrollment in relation to other early career alternatives. Such research can inform interventions that promote advanced study in engineering, especially given the applied nature of the field and the fact that growth in science and engineering degrees is higher at the master's level (57%) than at the bachelor's (39%) or doctoral levels (38%) (National Science Board, 2014).

Thus, in this paper we examined key factors that contribute to engineering postgraduates' decisions regarding graduate study soon after bachelor's degree completion. More specifically, we explored the influence of (1) engineering postgraduates' mathematics proficiency prior to college, (2) their self-assessments of their skills during college, and (3) their college experiences, on graduate school attendance in engineering or in other fields within three years after receiving a bachelor's degree.

Three Approaches to Explaining Graduate School Attendance in STEM

Previous research suggests three different explanations of how students in STEM fields choose to pursue, persist, and complete STEM graduate degrees: (1) supply attributes; (2) matching between qualifications and interests; and (3) demand factors (Lowell, Salzman, Bernstein, & Henderson, 2009). The first perspective suggests that if students are proficient in

mathematics and science at an early age, this proficiency encourages them to choose STEM undergraduate and graduate schools as well as STEM employment (Seymour & Hewitt, 1997). For example, students who take trigonometry, pre-calculus, or calculus in high school are more likely to attain STEM degrees than their peers (Chen & Weko, 2009). Conversely, high school students who only take lower levels of math or science are not able to choose a major in engineering or an engineering career due to admissions or degree requirements (Bozick & Ingels, 2007). Researchers also argue that many students may decide their career goals in high school, and thus elect to take math and science courses in preparation for such a career (Antony, 1998; Federman, 2007).

Most research addressing the low enrollment of underrepresented minority students (URM) in STEM fields identifies academic preparedness in mathematics as one of the most salient factors influencing their choice of graduate school in engineering (Dix & National Research Council, 1987; Anderson & Kim, 2006). In addition though, Adelman (1998) argued that high-achieving women engineering students are especially likely to switch fields to avoid competition with male students. Stereotype threat and unwelcoming climates for women and URM students lead them to believe that they can be more successful in fields where they are not traditionally regarded as a minority group (Adelman, 1998; Steele, James, & Barnett, 2002). Furthermore, although students with above-average math proficiency are more likely to attend STEM-related graduate programs, research indicates that this proficiency does not tend to influence students' persistence in graduate school and doctoral degree completion (Herzig, 2004; Bair & Haworth, 2005).

The second perspective suggests that students choose STEM graduate education based not only on their qualifications but also their interests, self-efficacy, self-confidence, and self-

esteem in relation to specific disciplines. In his social cognitive learning theory, Bandura (1986) defined self-efficacy as an individual's judgments of her abilities to accomplish specific tasks or objectives, and argued that self-efficacy mediates between actual ability and career choice. Using self-efficacy theory, both Wang and Staver (2001) and Mau (2003) found that career aspirations and interest in engineering disciplines during college influence persistence in engineering professions. For example, a student may have high ability in mathematics and science, but without self-efficacy her career or graduate school choice may exclude engineering fields. Thus, the low number of women and underrepresented minority students in engineering graduate programs might be related to self-doubt and/or loss of self-esteem during their undergraduate education (Anderson, 1994; Marra, Rodgers, Shen, & Bogue, 2009).

Although researchers have paid attention to the relationships between self-efficacy and graduate school choice, self-assessed abilities or skills have not received as much focus. Some researchers treat reports of self-efficacy as equivalent to self-estimated or self-rated abilities, given that both involve people's beliefs about their personal capabilities (e.g., Tracey & Hopkins, 2001). In contrast, other researchers distinguish self-rated abilities in certain knowledge and skill areas from self-efficacy (Brown, Lent, & Gore, 2000; Bong & Skaalvik, 2003). In the development of vocational interests and choices, *self-rated abilities* were defined as normative judgments about one's *current* work-related abilities (Swanson, 1993). For example, some researchers measured self-rated abilities by asking respondents to compare themselves to others of their own age on artistic ability, scientific ability, and so forth, using a scale from "low ability" to "high ability" (Brown, et al., 2000; Swanson, 1993). On the other hand, *self-efficacy* was defined as a reflection of an individual's expectations about *future* performance in specific tasks and environments that are based on judgments of capabilities (Lent & Brown, 2006; Lent et al.,

1994). For example, Marra et al. (2009) measured female engineering students' self-efficacy using questionnaire items such as "I can succeed in engineering curriculum". Brown et al. (2000) summarized this distinction, explaining that self-efficacy focuses on prospective or future-oriented performance capabilities, whereas self-rated ability focuses on judgments about current abilities.

The third perspective looks to demand or market forces, arguing that labor markets attract students to career paths that will best compensate them for their abilities (Lowell & Salzman, 2007; Lowell, et al., 2009). Lowell et al. (2009) argued that high-performing undergraduate students frequently choose not to continue their graduate education in STEM because of the high starting salaries available to them. Teitelbaum (2001) attributed this problem to a long period of training that results in few employment opportunities involving research and in relatively low wages compared to other professions, such as medicine, law, and business, thus making doctoral careers unattractive to engineering graduates. Also, market incentives tend to be more influential in the graduate-school decisions of those students whose parents have lower levels of income and education, and cultural and social capital (Perna, 2004). Given the connection between race and socioeconomic status in the United States, underrepresented minority students might be particularly sensitive to market incentives. Pearson Jr. (1987) suggested that certain minority groups tend to choose immediate employment after college graduation rather than advanced study given 1) the prospects of further financial difficulties; 2) the academic risk of graduate study; and 3) labor market uncertainties (Pearson & Fechter, 1994).

In sum, scholars suggests that rigorous academic preparedness in mathematics and science, good matching between qualifications and interests, and market incentives encourage students to continue their graduate education in engineering programs. Yet, while these

explanations may help demonstrate the choice of graduate fields, researchers have not yet considered the potential impacts of STEM students' self-assessment of their skills and educational experiences and on their graduate education choices.

Students' Self-assessment of Skills

Although previous studies examined the relationship between self-efficacy and engineering students' graduate school enrollment, little research has explored whether students' rating of their engineering skills contribute positively or negatively to their choice of engineering in graduate school. Holland (1997) theorized that individuals choose occupations that are consistent with their vocational aspirations, interests, competencies, and self-rated abilities. Exploring the relationships among interests, competencies, and self-rated abilities, Holland (1997) found positive correlations between students' interests in scientific occupations and their scientific competencies. However, the causal direction between competencies and interests in occupations is unclear.

Astin and Astin (1992) examined factors that influenced first-year college students' interests in studying science and in pursuing science-related careers and graduate school. Their research indicated that the most powerful predictor of students' interest in science majors and careers was their entering level of mathematical or academic competency. Similarly, Sax (1994) found that self-ratings of math ability were a significant predictor of retention, which is presumed to influence persistence on paths to careers in engineering. In an experiment with undergraduate students, Correll (2004) found that students who reported higher assessments of their own mathematical ability were more likely to pursue engineering and science careers than other counterparts.

In addition to self-assessment of mathematical ability, self-evaluation of other desired engineering skills might influence students' persistence in engineering graduate school and related careers. In response to industry demands and changes in professional program accreditation standards, engineering instructors and faculty members are redesigning engineering education to emphasize not only mathematical, scientific, and technical knowledge but also professional skills and contextual consideration in engineering practice (ABET Engineering Accreditation Commission, 2008; National Academy of Engineering, 2004; 2005). Sheppard et al. (2010) asked engineering seniors to rate their abilities and knowledge in comparison to their classmates, and found that senior students with greater confidence in their professional and interpersonal skills were less likely to pursue engineering careers or engineering in graduate school. This finding is intriguing, suggesting that students with more confidence in what are sometimes called "soft" skills gravitate toward careers in industry. This research, however, had two key limitations: 1) the research design did not take into account students' confidence in other important engineering skills that the engineering community has emphasized (e.g., design skills, contextual competence, and interdisciplinary skills); and 2) the study measured seniors' post-graduate *plans* rather than their subsequent career or study choices.

The Importance of College Experiences

Higher education researchers have long emphasized the role of co-curricular engagement on graduate school attendance and graduation (Pascarella & Terenzini, 2005). Research on learning and motivation suggests that situational interests, such as those created by student participation in certain co-curricular activities, may become intrinsic interests over time (Hidi, 1990; Renniger, 2000). Variations in co-curricular engagement might influence students'

interests and confidence in particular areas, and thus their choices regarding graduate study and careers.

Among diverse co-curricular activities, previous studies suggest that involving students in undergraduate research promotes their subsequent pursuit of advanced study in STEM fields (Heath, 1992; Kremer & Bringle, 1990; Lopatto, 2004; Strayhorn, 2010). Because undergraduate research experiences promote research knowledge and skills (Lopatto, 2007; Seymour, Hunter, Laursen, & DeAntoni, 2004), research self-efficacy (Adekokun, Bessenbacher, Parker, Kirkham, & Burgess, 2013), satisfaction with engineering (Bauer & Bennett, 2003; Seymour, et al., 2004), and networking and interaction with faculty members (Astin & Astin, 1992; Kardash, 2000), policy makers and educators believe that these experiences help students to prepare for graduate education (Boylan, 2009). Using data from the Cooperative Institutional Research Program on 1,634 underrepresented minority students in 217 institutions, Chang, Sharkness, Hurtado, and Newman (2014) found that participation in undergraduate research programs increases the likelihood that underrepresented minority students persist in STEM undergraduate majors.

Other co-curricular activities are also considered to increase student interest, promote interactions with peers and faculty, and develop better climates for students in both STEM and non-STEM fields (Gellin, 2003; Pascarella & Terenzini, 2005). For example, exploring a single institution, Linn, Ferguson, and Egart (2003) found that sampled graduates were likely to take post-graduate jobs in occupational fields they had explored during cooperative education experiences; this finding is consistent with previous research (e.g., Leventman & Horst, 1985). In a qualitative study of 76 STEM seniors and 55 faculty advisors at four highly selective liberal arts colleges, Thiry, Laursen, Hunter (2011) found that internships and clinical programs offered

students ownership of a real-world project, helping them to clarify future career goals and develop their professional identities. Service learning and community service also contributed to improved social engagement, problem solving and professional skills among engineering students (Smith, Sheppard, Johnson, & Johnson, 2005; Shuman, Besterfield-Sacre, & McGourty, 2005; Tempest, Dika, Pando, & Lopez, 2012). Since co-curricular experiences may also influence decisions regarding graduate education (Anakwe & Greenhaus, 2000), researchers should examine the impact of co-curricular participation on graduate education enrollment.

Based on theory and research regarding supply attributes, alignment between qualifications and interests, and the impact of college experiences, we explore three research questions:

1. Controlling for individual and institutional characteristics, to what extent does graduates' *mathematics proficiency prior to college* influence graduate school enrollment in engineering?
2. Controlling for individual characteristics and institutional characteristics, to what extent do graduates' *assessments of their engineering abilities during college* influence graduate school enrollment in engineering?
3. Controlling for individual characteristics and institutional characteristics, to what extent do graduates' *co-curricular experiences during college* influence graduate school enrollment in engineering?

Method

Design, Population, and Sample

We use data from the [BLIND FOR REVIEW] study. Supported by the National Science Foundation, the study investigates the effects of curricular, instructional, and organizational

practices on student learning. Data were collected from 30 four-year colleges that are representative of all four-year U.S. engineering schools offering two or more ABET-accredited programs in the following seven engineering disciplines: biomedical/bioengineering, chemical, civil, electrical, general, industrial, and mechanical. In the aggregate, these programs accounted for 70% of all baccalaureate engineering degrees awarded in 2007. The stratified sample design of institutions was also representative according to highest level degree offered (bachelor's, master's, or doctorate), and type of institutional control (public or private).

The postgraduate population was defined as all individuals who earned a bachelor's degree during the academic year 2005-2006 in one of the focal engineering disciplines at the sampled institutions. All postgraduates meeting the study's population specifications were invited to participate. Chi-square goodness-of-fit tests indicated that postgraduates at the participating institutions were marginally unrepresentative of the overall population of engineering postgraduates: population-sample differences ranged from 1 to 13 percentage points (Table 1). Consequently, individual weights were created to adjust for any campus-specific response bias based on postgraduate respondents' gender, race/ethnicity, and engineering discipline, as well as for differing response rates across institutions. An overall weight was calculated (by multiplying these individual weights) and applied to all postgraduate respondents to produce a sample that can be considered representative of the population of engineering postgraduates as specified, both on each campus and nationally.

[Table 1]

Invitations to participate were sent to 7,307 postgraduates during the spring and summer terms of 2009, of whom 1,403 responded (19%). Conversations with colleagues around the country indicate that such a response rate is not uncommon in multi-institutional studies. Survey

response rates, moreover, have been in decline for several decades (Baruch 1999; Dey 1997; Smith 1995), and web-based surveys often have relatively low response rates (Porter & Umbach, 2006; Van Horn, Green, & Martinussen, 2009). Still, the low response rate, despite corrective weighting, may pose non-trivial threats to the external validity of the study's findings. A series of chi-square goodness-of-fit tests in terms of gender, race/ethnicity, and disciplines determined the representativeness of the sample for the populations that received the survey at each institution. However, more extensive analyses could not be conducted to determine representativeness because institutions provided only data related to these variables for their postgraduates.

Missing data were imputed following procedures recommended by Dempster, Laird, and Rubin (1977) and by Graham (2009), using the Expectation-Maximization (EM) algorithm of the Statistical Package for the Social Sciences (SPSS) software (v.18). Given that this study is focused on domestic engineering postgraduates, we did not examine data from 71 foreign nationals. Foreign national student groups tend to be heterogeneous, and more detailed data are not available to demonstrate the groups' characteristics, such as when they moved to the U.S., whether they attended high schools in the U.S., or their race/ethnicity along with their citizenship. We also do not include 104 engineering graduates receiving or attending graduate schools for both engineering and non-engineering graduate degrees since the interpretation for their career path is not clear. We include this limitation in the Discussion section for a future research idea. After these restrictions, our final sample includes 1,119 engineering postgraduates. Of these, 455 were either enrolled in or had completed an engineering graduate program, 156 had enrolled in or had completed a graduate program outside engineering, and 508 were working in engineering and had not yet enrolled in any form of graduate education.

Measures

Instrument Development. A team of education and engineering researchers collaborated on instrument development, beginning with an extensive literature review on topics related to critical college experiences and key learning outcomes identified by the National Academy of Engineering's (2004) *Engineer of 2020* report. In addition to providing conceptual guidance for survey development, findings from this literature review generated a bank of potential survey items related to engineering students' college experiences and learning outcomes. In cases where available scales had acceptable psychometric properties, items were adopted or minimally revised. The team also conducted interviews and focus groups with engineering administrators, faculty members, students, and alumni at the following five campuses to develop new survey items and ensure appropriate coverage of key topics: BLIND FOR REVIEW. Drafts of potential survey items were reviewed by engineering faculty and administrators to evaluate and refine the survey, and the instrument was pilot tested with students at BLIND FOR REVIEW and BLIND FOR REVIEW ($n = 482$) for newly developed items. The research team used factor analysis techniques to explore pilot results and further revised survey items based on these findings. The team again met with focus groups of engineering faculty members and administrators from BLIND FOR REVIEW to review the revised student survey and assess its construct validity (i.e., whether the items represent their intended purpose; Shadish, Cook, & Campbell, 2002) before administering the final version. To provide a more compact, aggregated summary of the individual-items, the team used factor analysis and selected the principal axis factoring method (oblimin with Kaiser normalization rotation). This statistical procedure determined the degree of correlation between items, and highly-correlated items were combined to form scales. Items were assigned to scales based on the magnitude of loading from the principal axis analysis method, the

effect of keeping or discarding the item on the scale's internal consistency reliability, and professional judgment. As recommended by Armor (1974), scales were computed by summing respondents' scores on component items and dividing the sum by the number of items in the scale.

Variables. Attendance in engineering graduate programs is the criterion measure. Engineering postgraduates reported on their current enrollment in engineering graduate programs as well as graduate degree completions; both groups are included in our measure. The degree programs varied between the master's and Ph.D. levels; because we are interested in graduate education generally, we combine master's and doctoral degree enrollments/degrees in our analysis. The dependent variable thus has three categories: 1) currently enrolled in or received a graduate degree in engineering, 2) enrolled in or received a degree in a graduate program outside engineering, and 3) working and not currently or formerly enrolled in any graduate program.

The analytical variables in this study fell into two groups: control (covariates) and independent variables. In order to remove potentially confounding effects related to the characteristics of the institutions that were home to the engineering disciplines and engineering graduates under study, controls were made for institutional size and highest degree awarded (doctorate, master, or bachelor). Several prior student characteristics are also controlled for: gender, race/ethnicity, parental educational level, high school GPA, college GPA and SAT verbal score.

Three sets of independent variables are used: proficiency in mathematics (SAT math score), co-curricular participation, and self-assessments of skills during each postgraduate's undergraduate year. Co-curricular experiences consist of five single-item measures: (1) the number of months students reported spending on undergraduate research, (2) months spent on

engineering internships, (3) months spent on cooperative educational experiences, (4) months spent on community service or volunteer work, and (5) the extent of postgraduates' involvement in an engineering club or student chapter of a professional society during their undergraduate experience.

Six self-assessments of skills as undergraduate seniors were also used: design skills, contextual competence, interdisciplinary skills, teamwork skills, communication skills, and leadership skills. *Design skills* (12-item scale, Cronbach's $\alpha = .86$) included the solving of ill-structured problems, creative approaches, non-technical considerations, and critical skills as identified in the BLIND FOR REVIEW engineering accreditation criteria (ABET Engineering Accreditation Commission, 2008). *Contextual competence* (4-item scale, Cronbach's $\alpha = .90$) assessed graduates' ability to solve engineering problems in real-world contexts (ABET Engineering Accreditation Commission, 2008). *Interdisciplinary skills* (eight-item scale, Cronbach's $\alpha = .86$) assessed graduates' ability to work across disciplines both within and outside the field of engineering (NAE, 2004). *Teamwork skills* include self-assessments of working in teams of people who have different skills and backgrounds as well as people from fields outside of engineering (5- item scale, Cronbach's $\alpha = .86$). *Communication skills* measures graduates' self-assessments of not only oral and written communication but also effective communication with people from different cultures or countries, and from outside engineering (6- item Cronbach's scale, $\alpha = .87$). *Leadership skills* assessed graduates' ability to develop plans, take responsibilities, and monitor process to ensure goals are being met (6-item scale, Cronbach's $\alpha = .90$). Among those learning outcomes, we documented the contextual competence and interdisciplinary skills scales' validity and reliability in (BLINDED FOR

REVIEW). Copies of these instruments are available at (BLINDED FOR REVIEW). Appendix 1 provides operational information on all variables' contents and metrics.

Analytical Procedures

Using a hierarchical multinomial logistic model (HMLM), we examine the unique contributions of students' math proficiency prior to college, college experiences, and self-assessment of abilities during college years on graduate school attendance. Although a multilevel analysis is not the primary research interest of this study, the HMLM method has important benefits. Using a multinomial logistic regression model would misestimate standard errors by not taking into account the correlations between individuals within the same institutions. Thus, standard logistic regression will violate the assumption of complete independence of observations and lead to biased estimates of standard errors. In contrast, the HMLM method enables us to adjust for clustering within institutions.

We use a Bernoulli model because our dependent variable ($y = 1, 2, 3$) is non-ordered and categorical, where the respective values of y refer to 1) currently enrolled in or received degree in engineering graduate school, 2) currently enrolled in or received degree outside of engineering graduate school, and 3) working without any graduate study. Level 1 is the individual level; in our HMLM analysis, this outcome functions as a dependent variable predicted by institutional characteristics at level 2. The institution-level variables, however, are treated as covariates (control variables) rather than as predictors in this study.

This study uses odds-ratios to facilitate the interpretation of results. Odds ratios are the comparison of the probability of one event occurring versus another. Using $y = 3$ as the baseline outcome, in the results section we report the impact of control and independent variables in predicting first outcome $y = 1$ in relation to $y = 3$ and then $y = 2$ in relation to $y = 3$ by presenting

each variable's coefficient and corresponding odds ratio. In each case, the odds ratio represents the change in the odds of the given outcome relative to $y = 3$ that is associated with a one-unit change in a specific independent variable while holding all other variables constant. An odds ratio greater than one represents an increase in the likelihood of attending engineering graduate school relative to not enrolling. An odds ratio of less than one represents a decrease in the likelihood of engineering graduate school attendance. In each model, the coefficients (β) are the natural logs of their respective odds ratios; hence, odds ratios (OR) can be produced from coefficients by performing the transformation: $OR = e^{\beta}$. Odds ratios are not linearly additive. In order to compare the relative effect of odds ratios greater than one to those less than one, we take the inverse of the latter (DesJardins, 2001).

Limitations

Like all studies, this one has its limitations. First, the postgraduate data are cross-sectional rather than longitudinal. Engineering postgraduates had to rely on their recollections of their engagement in co-curricular activities and the self-assessment of their skills when they were in undergraduate programs. The self-ratings are likely to be at least partially influenced by respondents' current work status. It is worth noting though that the survey asked respondents for their abilities during both their senior and current years. With this format, respondents might be able to assess their prior abilities away from their current abilities. However, we admit the limitation that their senior-year abilities could be relative to their current ones. To solve this limitation, a longitudinal study is required to measure graduates' college experience and current graduate school enrollment. Furthermore, given the cross-sectional nature of the study, it is not tenable to view our results as demonstrating a causal relationship.

Second, there are limitations due to the (BLINDED FOR PEER REVIEW) survey that we used. We have just a single measure of students' math proficiency – SAT score – prior to college study. As with most any single assessment, SAT scores cannot provide a complete measure of math ability, and there are concerns that it is biased against students from lower socioeconomic status and minority backgrounds (Dixon-Román, Everson, & McArdle, 2013; Freedle, 2003; Guinier & Torres, 2002). The fact that we rely on students' aggregate score on a single assessment curtails our ability to conduct more nuanced analyses of which specific sub-areas of math proficiency prior to college might be especially important to students' subsequent pathways into graduate study.

Third, although the survey is large and comprehensive, it does not include postgraduates' financial information. For example, postgraduates' parental financial support for their education, socio-economic status (the data has educational level but not income level), and funding opportunities and employer contributions for education, all of which are likely to influence their decision making for graduate education. Furthermore, one of the outcome-measure categories, graduate school choice for other programs, was not divided into subcategories such as business school, law school, or medical school. Engineering postgraduates who choose business school and medical school probably have distinctive reasons and motivations for pursuing these advanced degrees. The survey also did not ask whether the postgraduates were currently enrolled or had ever enrolled part-time (generally taking one course per semester). Hence, this study could not catch all possibilities of the different patterns of enrollment at graduate schools.

Fourth, this study examines graduate school enrollment and workforce patterns of postgraduates who are three years out of their undergraduate programs. Engineering postgraduates may decide to enroll in graduate study after a longer period of employment in the

field. In particular, postgraduates wishing to pursue an MBA degree as fulltime generally need to have four or more years of full-time work experience before admission; this group would have been missed in this study. This matters because the impact of academic disciplines and experiences might differ depending on when graduates return to graduate education.

Finally, we are not able to examine the demand approach, which has been advanced as one determinant of the career paths of college graduates. As a result, one immediate cause for concern is our failure to account for outside influences such as the effects of changes in the engineering industry or the condition of economic downturns on graduate school attendance. Our conceptual framework is necessarily a simplification of reality; however, our analysis is able to explore the usefulness of this framework as it relates to the impact of colleges on engineering postgraduates' graduate school attendance.

Findings

Table 3 and Table 4 present findings from the HMLM analysis. Table 3 shows coefficients and corresponding odds ratios for the independent variables when comparing outcome 1 (currently enrolled in or received degree in engineering graduate school) to outcome 3 (working without any graduate study). The coefficients, and corresponding odds ratios, in Table 4 compare outcome 2 (enrolled in or received degree in a graduate program outside engineering) to outcome 3. Both sets of results come from a single multinomial model, which controls for individual demographic and institutional characteristics already mentioned.

[Table 3]

Regarding Table 3, SAT math score is a significant positive predictor of enrollment in engineering graduate study. This result is despite our controls controlling for SAT verbal score and academic GPA. The odds ratio for the SAT math variable is 1.006, which is based on the

change associated with just a one-point increase in SAT math score. By extension, a 100-point increase in SAT math score is associated with an odds ratio of 1.6, i.e. a 60% increase in the likelihood of attending engineering graduate school. This is a plausible scale of increase given the standard deviation in SAT math score in our sample is 76 (Table 2).

Of the co-curricular activities, only undergraduate research is a significant predictor; the relationship is positive, with each additional month of undergraduate research increasing the likelihood of enrollment in engineering graduate study by four percent. Among the abilities and skills variables, teamwork skills and leadership skills were both significant. Whereas teamwork skills had a negative impact on the outcome, leadership skills had a positive impact: on average, a one unit increase in students' self-assessments of their teamwork skills on a five-point scale led to a 37% drop (inverse odds-ratio=1.367) in the likelihood of enrolling in engineering graduate study, whereas a one unit increase in leadership skills led to a 62% increase (odds-ratio=1.618). No other abilities and skills provided significant non-negative estimates.

[Table 4]

As Table 4 shows, SAT math score is also a predictor of graduate study outside engineering, although this variable has a far larger standard error than in the previous model (Table 3), making it only just significant at the .05 level. Other significant predictors differ from those for graduate study in engineering. For co-curricular activities, undergraduate research no longer has a significant impact. Instead, the model indicates that participation in non-engineering community service (or volunteer work) was a positive predictor of enrollment in graduate study outside of engineering, in comparison to no graduate study. A one week increase in engineering graduates' participation in non-engineering related community service or volunteer work led to a

two percent increase. None of the independent variables related to abilities and skills provided significant non-negative estimates.

In sum, the impact of the independent variables in our model varied considerably depending on whether postgraduates' graduate study did or did not focus on engineering. Given that the measures of self-assessments of skills are closely related to engineering context, we found that their self-beliefs in senior year, such as in teamwork and leadership skills, influence their likelihood of enrolling in graduate study in engineering, but not in other fields of study. While undergraduate research experiences positively relate to graduate school enrollment in engineering, participation in clubs and volunteer work positively relates to graduate study in other fields.

Discussion and Implication

The question of graduate school attendance is a critical one for the field of engineering. This study aims to investigate how engineering postgraduates' math proficiency prior to college, self-assessments of skills during and co-curricular participation during college relate their attendance in graduate school in engineering or non-engineering. We discuss the important findings of our study and provide several implications for future studies and for policy and practice based on the findings.

Discussions

Existing research emphasizes three influences on decisions to pursue graduate study in STEM: supply attributes, matching between qualifications and interests, and demand factors. Our first research question focused on the supply attributes explanation. We confirmed that mathematics proficiency prior to college, as measured by SAT mathematics scores, influences enrollment in graduate programs, both within and outside of engineering. However, the

respective significance levels ($p < .001$ for within engineering, $p < .05$ for outside of engineering) make us more confident in asserting that prior math proficiency matters to graduate school within engineering than to other fields of graduate study. This result is important to access for historically underrepresented racial minority groups because prior research has shown that SAT math scores differ by racial/ethnic groups. For example, research usually calls attention to African American students' lack of math preparation for collegiate mathematics courses (McGee & Martin, 2011), which ultimately can influence their graduate school choice in STEM fields. Issues of social and cultural capital must also be considered though, as access to the preparation math courses and performance level of SAT math scores are tied to larger contextual factors such as parental education and expectations, school location and resources, and the distribution of household wealth (Oakes, 2003).

Interestingly, SAT verbal scores, as a proxy for verbal ability, were not significant predictors for engineering graduate school choice, but were significant predictors of enrollment in non-engineering graduate school programs. This result is based on our analyses that controlled for race as well as gender. This supports previous research identifying academic preparedness in mathematics as one of the most salient factors influencing graduate school attendance, in particular for historically underrepresented students in science and engineering (Huang, Taddese, & Walter, 2000).

Our second research question explored whether a match between interests and qualifications influenced graduate school attendance in engineering. We included measures of students' engagement in a variety of co-curricular activity and graduates' self-reports of their engineering abilities during undergraduate education to operationalize the concepts associated with the "interests and qualifications" hypothesis. We address each set of variables in turn.

Individuals' interests in engineering graduate study appear to be related to co-curricular engagement during undergraduate study. The more time students spent in undergraduate research, the more likely they were to be enrolled or have completed a graduate program in engineering. This pattern is consistent with previous studies on the impact of undergraduate research on graduate school enrollment (e.g., Lopatto, 2007; Boylan, 2009) and their intention to enroll in a STEM graduate program (Eagan, Hurtado, Chang, Garcia, Herrera, & Garibay, 2013; Jiang & Loui, 2012). Our finding also supports the notion that undergraduate research is an effective tool to increase students' interests in graduate studies within engineering fields.

The more time undergraduate engineers spent in non-engineering related community service or volunteer work, the more likely they were to have attended or be enrolled in a graduate program outside of engineering within three years after graduation. Engineering undergraduates who participate in these types of activities may have interests outside the field that they cultivate during their studies, or they may become interested in other fields or occupations as a result of their involvement in non-engineering activities. Pursuing a graduate program outside engineering, however, does not necessarily indicate that an individual leaves the field. We found that 66% of students who choose master's degrees outside of engineering took management or business-oriented master's programs. This may suggest that such students want to prepare themselves for leadership positions within engineering rather than new career directions outside of engineering. Future research might explore how different kinds of co-curricular involvement shape ideas about careers and what kinds of preparation during college are needed for different career paths.

Our analysis on postgraduates' self-ratings of several engineering skills permitted a fine-grained look at how different kinds of qualifications influence graduate study in the field, and

our findings indicate that high levels of confidence in different engineering skills have different effects on graduate school attendance within the field. Postgraduates who reported higher teamwork skills were less likely to have attended or be currently enrolled in an engineering graduate program three years after graduation. In contrast, higher self-reported leadership skills increased the probability that a graduate had completed or was enrolled in an engineering graduate program within three years of receiving a bachelor's degree. These findings appear generally consistent with theories of vocational choice positing that individuals gravitate toward careers consistent with their vocational aspirations, interests, competencies, and self-perceptions (Holland, 1997). Our findings regarding graduates' perceptions of their qualifications for graduate study are also largely consistent with the predictions of self-efficacy theory. Engineering postgraduates who perceive they have superior teamwork skills appear to focus their attention on applying those skills in engineering practice and may seek to advance in the profession through work rather than by pursuing graduate studies during their early career. Postgraduates who reported high levels of confidence in leadership skills during their undergraduate year might choose graduate school in their early career path to prepare for higher positions in engineering industry.

Implications for future study

One important question our study cannot answer is how graduate study in fields outside engineering may complement undergraduate study in the field to advance one's career in engineering. Pursuing a graduate program outside engineering is not necessarily a signal of an individual's intention to leave the field. Indeed, since management skills are critical to career advancement in technically oriented industries, many engineers pursue graduate studies in business to continue their careers within these fields. Similarly, individuals may pair an

undergraduate degree in engineering with graduate study in medicine or science to prepare for work in biomedical engineering. National agencies should support future research to understand why engineering graduates pursue advanced education in other fields, in order to further promote domestic production of human resources and help individuals attain their educational and career goals.

It is important to note though that because we are reporting on graduate school attendance three years after the attainment of the undergraduate degree, we are likely to underestimate the numbers of engineering graduates who eventually pursue graduate study in the field. This study also does not include 104 graduates who had received and attended graduate schools for both engineering and non-engineering graduate degrees. This group might have strong interests and qualifications for interdisciplinary learning. Future research needs to investigate which kinds of college experiences and qualifications encourage engineering graduates to choose between engineering and non-engineering graduate education.

Since graduates' perceptions of the curricular emphasis placed on particular engineering knowledge and skills were not significant influences on graduate education in engineering based on our previous study (Authors, 2010), we did not include the impact of curricular experience in this study. Future research, however, should examine the undergraduate educational experience more deeply, examining the influence of instructional methods and classroom climate, as well as course content, on graduates' decisions to attend graduate education. For example, students in programs with relatively stronger emphases on professional skills and values might tend toward engineering employment after graduation (Kranov, Hauser, Olsen, & Girardeau, 2008; Nehdi & Rehan, 2007). Collaborative and problem-based learning in engineering courses may influence

students' interests and confidence in professional and interpersonal skills, and ultimately their decisions about graduate school attendance in engineering.

We also suggest several future research ideas based on the limitation of our data. First, nationally representative, multi-institutional, and longitudinal data should be collected. As the data we used were cross-sectional, we cannot assume that the relationship between self-assessed skills and engineering graduate school choice as causal. Longitudinal data could be designed to ask engineering senior students to report their college experience and assess their knowledge and skills, and then to measure their graduate school choice pattern after three and seven years for both early and middle career path. Such data should collect a finer-grained pattern of graduate school choice, such as part-time and full-time enrollment status, and specific categories of non-engineering graduate programs. Future research also should investigate how students support the tuition for their graduate school study, which must relate to students' socioeconomic status.

Implications for practice and policies

This study also has implications for policy and practice in three areas: (1) students' math proficiency prior to college education, (2) disciplinary domain knowledge and skills during college, and (3) co-curricular programs. In our models, the explanatory power of SAT math scores is considerable, even after controlling for performance during undergraduate study. This result suggests that one of the most effective policy mechanisms to increase the numbers applying to graduate school programs in engineering is to improve the quality of math education at the K–12 level. Of course, this is easier said than done, as evidenced by the vast body of research on this subject (see, for example, Ball & Forzani, 2009; Dee & Jacob 2011; Hoxby, 2000; Porter, McMaken, Hwang, & Yang, 2011). While the having a single measure of pre-

college math ability precludes us from engaging with such debates, we are able to provide further evidence for the importance of persisting with this policy challenge.

It may be equally important, however, to help high school and college students understand that more than mathematics proficiency alone is required for engineering practice and advancement, as many national reports on engineering education make clear (e.g., NAE, 2004; Jamieson & Lohmann, 2012). In response to industry demands and changes in professional program accreditation standards, engineering instructors and faculty members are redesigning engineering curricula to emphasize not only mathematical, scientific, and technical knowledge but also professional skills in engineering practice. This study confirms that students' leadership competence and interests in management or leadership positions drive them to choose graduate education in engineering fields. Administrators and faculty members should incorporate leadership components in engineering curricula to encourage them to become leaders in science and technology fields. Students who have high confidence in teamwork skills might mistakenly believe that their competence is not an advantage when pursuing graduate study. STEM faculty members should convey the message that graduate work in STEM fields requires not only individual work but also teamwork, based on collaborative and interdisciplinary research teams and collaboration with real clients.

These findings have implications for student affairs professionals, including undergraduate research advisors and others who facilitate students' learning outside of classroom. Faculty members and undergraduate research advisors can help students gain insights into what STEM-related graduate study, and careers, entail by promoting undergraduate research opportunities. Student affairs professionals can also contribute to students' graduate school choices in STEM fields by creating co-curricular opportunities for them to acquire and

hone their professional skills. Co-curricular programs that are directly related to learning in STEM contexts will help develop student interest and confidence to pursue STEM graduate study and careers.

Conclusions

STEM undergraduate and graduate programs have played a key role in maintaining the United States as a global leader in science and technology. To compete with countries such as China and India, however, the U.S. has requested that higher education develop interventions to improve the quantity and quality of STEM human resources. This study confirms that higher math proficiencies, higher ratings of one's abilities in certain skills, and participation in certain co-curricular programs influence graduate school attendance. Although this study provides a new approach to exploring the impacts of educational experiences and self-beliefs during college on graduate study, more research is needed to understand the pipelines issues between undergraduate education and graduate education as well as workforce upon graduation in the STEM fields.

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Tables

Table 1. Characteristics of the population of 2006 engineering postgraduates, survey respondents, and their institutions

Characteristic	288- Institution Population ^a (n = 50,201)	30- Institution Sample ^a (n = 8,294)	Respondents (weighted and imputed) ^b (n=1,420)
Individual			
Discipline			
Biomedical	5.7%	5.6%	6.3%
Chemical	8.5	12.2	9.1
Civil	17.1	16.5	14.8
Electrical	28.0	22.6	32.1
Industrial	7.2	7.4	8.1
Mechanical	31.2	31.1	24.3
General	<u>2.3</u>	<u>2.5</u>	<u>5.3</u>
	100.0%	100.0%	100.0%
Gender			
Male	79.9%	73.7%	79.3%
Female	<u>20.1</u>	<u>26.3</u>	<u>20.7</u>
	100.0%	100.0%	100.0%
Race/Ethnicity			
African American	4.7%	2.9%	5.3%
Asian or Pacific Islander	12.7	6.9	15.6
Hispanic	6.7	4.3	7.4
American Indian/ Alaskan			.1
Native	.5	.1	
Other	7.1	8.6	3.8
Foreign	6.9	2.4	6.6
Caucasian	<u>61.3</u>	<u>74.7</u>	<u>61.2</u>
	100.0%	100.0%	100.0%

^a Source: American Society of Engineering Education.^b Weighted by gender, race/ethnicity, discipline, and adjusted for institutional response rate.^c Weighted n may be smaller than unadjusted number of respondents due to missing data on a weighting variable.

Table 2. Descriptive statistics for the sample (n = 1,201).

	Mean or %	S.D.	Min.	Max.
Dependent variable				
Currently enrolled in or received degree in engineering graduate school	38%			
Currently enrolled in or received degree outside of engineering graduate school	20%			
Working without any graduate study	42%			
Proficiency in mathematics				
SAT score	679.8	76.39	222	800
Co-curricular participation				
Undergraduate research	6.5	8.2	0	36
Engineering internships	5.4	6.7	0	36
Cooperative educational experiences	2.2	5.0	0	36
Non-engineering community service or volunteer work	9.1	12.1	0	36
Engineering club or student chapter of a professional society	2.3	1.3	1	5
Abilities and skills				
Design skills	3.2	0.7	1	5
Contextual awareness	2.8	0.9	1	5
Interdisciplinary skills	3.5	0.7	1	5
Teamwork skills	3.5	0.8	1	5
Communication skills	3.6	0.7	1	5
Leadership skills	3.2	0.8	1	5
Control variables				
Female	26%			
Racial/ethnic minority	24%			
Mother and/or father has at least a bachelor's degree	75%			
High school GPA at least 3.5	78%			
Engineering program GPA at least 3.5	39%			
SAT verbal score	603.1	91.1	222	800
<i>Holland typology of program</i>				
Realistic	56%			
Investigative	36%			
Enterprising	8%			
Large institution	10%			
Doctorate-degree awarding institution	44%			

Table 3. Individual-Level Predictors of Engineering Graduate School Attendance (n = 1,201).

Independent variables	β	SE		Odds-ratio	Inverse odds-ratio
<i>Math proficiency</i>					
SAT math score	0.006	0.002	***	1.006	
<i>Co-curricular participation</i>					
Undergraduate research	0.043	0.013	***	1.044	
Engineering internships	-0.014	0.017			
Cooperative educational experiences	0.029	0.024			
Non-engineering community service or volunteer work	0.013	0.010			
Engineering club or student chapter of a professional society	0.093	0.101			
<i>Abilities and skills</i>					
Design skills	-0.238	0.326			
Contextual awareness	-0.240	0.138			
Interdisciplinary skills	0.168	0.185			
Teamwork skills	-0.484	0.140	***	0.616	1.384
Communication skills	-0.045	0.164			
Leadership skills	0.503	0.221	*	1.654	

Notes: * $p < .05$, ** $p < .01$, *** $p < .001$. Reference dependent variable is no graduate study. Analytical model includes controls for institution and individual postgraduate's demographics. Odds ratios and inverse odds ratios are only provided for significant estimators.

Table 4. Individual-Level Predictors of Other Graduate School Attendance (n = 1,201).

Independent variables	β	SE		Odds-ratio	Inverse odds-ratio
<i>Math proficiency</i>					
SAT math score	0.005	0.003	*	1.005	
<i>Co-curricular participation</i>					
Undergraduate research	-0.001	0.012			
Engineering internships	-0.012	0.013			
Cooperative educational experiences	-0.002	0.025			
Non-engineering community service or volunteer work	0.016	0.008	*	1.016	
Engineering club or student chapter of a professional society	0.169	0.066	**	1.184	
<i>Abilities and skills</i>					
Design skills	0.338	0.319			
Contextual awareness	0.205	0.160			
Interdisciplinary skills	-0.377	0.290			
Teamwork skills	-0.373	0.227			
Communication skills	-0.377	0.220			
Leadership skills	0.368	0.306			

Notes: * $p < .05$, ** $p < .01$, *** $p < .001$. This dependent variable includes programs that were partially but not fully related to engineering. The reference dependent variable is no graduate study. Analytical model includes controls for institution and individual postgraduate's demographics. Odds ratios and inverse odds ratios are only provided for significant estimators.

Appendix. Study Variables

Variable	Coding
Dependent variable	
Postgraduate's graduate-school decision	Non-ordered categorical: 1) currently enrolled in or received degree in engineering graduate school, 2) currently enrolled in or received degree outside of engineering graduate school, or 3) working without any graduate study.
Independent variables	
<i>Proficiency in maths</i>	
SAT score	Continuous.
<i>Co-curricular participation</i>	
Undergraduate research	Continuous, measured in months.
Engineering internships	Continuous, measured in months.
Cooperative educational experiences	Continuous, measured in months.
Non-engineering community service or volunteer work	Continuous, measured in months.
Engineering club or student chapter of a professional society	Ordinal, 1=not active to 5=extremely active.
<i>Abilities and skills</i>	
Design skills	Factor consisting of student self-rating for 12 items: (1) evaluating design solutions based on a specified set of criteria; (2) generating and prioritizing criteria for evaluating the quality of a solution; (3) producing a product; (4) applying systems thinking in developing solutions to an engineering problem; (5) brainstorming possible engineering solutions; (6) taking into account the design contexts and the constraints they may impose on each possible solution; (7) defining design problems and objectives clearly and precisely; (8) asking questions to understand what a client/customer really wants in a 'product'; (9) breaking down a design project into manageable components or tasks; (10) recognizing when changes to the original understanding of the problem may be

	necessary; (11) developing pictorial representations of possible designs; and (12) undertaking a search before beginning team-based brainstorm. Each item is ordinal, from 1=weak to 5=excellent.
Contextual awareness	Factor consisting of student self-rating for four items: (1) using what you know about different cultures, social values, or political systems in developing engineering solutions; (2) recognizing how different contexts can change a problem solution; (3) knowledge of contexts that might affect the solution to an engineering problem; and (4) knowledge of the connections between technological solutions and their implications for the society or groups they are intended to benefit. Each item is ordinal, from 1=weak to 5=excellent.
Interdisciplinary skills	Factor consisting of student self-rating for eight items: (1) I can take ideas from outside engineering and synthesizing them in ways that help me better understand or explain a problem; (2) I can use what I have learned in one field in another setting or to solve a new problem; (3) I see connections between ideas in engineering and ideas in the humanities and social sciences; (4) I enjoy thinking about how different fields approach the same problem in different ways; (5) Given knowledge and ideas from different fields, I can figure out what is appropriate for solving a problem; (6) not all engineering problems have purely technical solutions; (7) In solving engineering problems I often seek information from experts in other academic fields; and (8) I value reading about topics outside of engineering. Each item is ordinal, from 1=strongly agree to 5=strongly disagree.
Teamwork skills	Factor consisting of student self-rating for five items: (1) working with others to accomplish group goals; (2) working in teams of people with a variety of skills and backgrounds; (3) working in teams where knowledge and ideas from multiple engineering fields must be applied; (4) working in teams that include people from fields outside engineering; and putting aside differences within a design team to get the work done. Each item is ordinal, from 1=weak to 5=excellent.
Communication skills	Factor consisting of student self-rating for six items: (1) writing a well-organized, coherent report; (2)

	making effective audiovisual presentations; (3) constructing tables or graphs to communicate a solution; (4) communicating effectively with clients, teammates, and supervisors; (5) communicating effectively with nontechnical audiences; and (6) communicating effectively with people from different cultures or countries. Each item is ordinal, from 1=weak to 5=excellent.
Leadership skills	Factor consisting of student self-rating for six items: (1) helping your group or organization work through periods when ideas are too many or too few; (2) developing a plan to accomplish a group or organization's goals; (3) taking responsibility for group's or organization's performance; (4) motivating people to do the work that needs to be done; (5) identifying team members' strengths/weaknesses and distribute tasks and workload accordingly; and (6) monitoring the design process to ensure goals are being met. Each item is ordinal, from 1=weak to 5=excellent.
Control variables	
Female	Dichotomous, 1=yes, 0=no.
Racial/ethnic minority	Dichotomous, 1=yes, 0=no.
Mother and/or father has at least a bachelor's degree	Dichotomous, 1=yes, 0=no.
High school GPA at least 3.5	Dichotomous, 1=yes, 0=no.
Engineering program GPA at least 3.5	Dichotomous, 1=yes, 0=no.
Holland typology of program	Non-ordered categorical: 1) realistic, 2) investigative, or 3) enterprising.
Large institution	Dichotomous, 1=yes, 0=no.
Doctorate-degree awarding institution	Dichotomous, 1=yes, 0=no.
